With private values the English, Japanese and Vickery auctions remain equivalent regardless of whether there is affiliation. None of our earlier reasoning which argued that the person with the top value would end up paying the valuation of the second bidder in either auction is affected by affiliation, so long as there are private values. Even if there are common values, so long as there are only two bidders the Japanese and Vickery auctions remain equivalent. In that case, the equilibrium bidding strategy for each person in the Japanese auction is to drop out of the bidding when the price reaches the true value of the asset, contingent on the other bidder having exactly the same estimate as you.[17] In a Vickery auction with two people, following the same strategy makes sense. But once there are three or more bidders (more than one bidder who will lose), the Japanese will yield the seller higher expected revenue than the Vickery.

Why does this happen? The difference is that with three or more bidders, the second highest bidder, who determines the actual price paid, will make a bid in the Vickery auction without having any information about the valuations of the third and lower bidders. He or she will have to make an estimate for those values and factor that into his or her own valuation so as to avoid getting hit by the winner's curse. The way in which to formulate the optimal sealed bid is to calculate the expected value of the property conditional on being tied for having the highest estimated valuation and that all other bidders have lower valuations. In estimating what values to assign to these other bidders, the person makes an estimate of the probability distribution for the third and lower bidders contingent on this second bidder actually being tied for first. But on average this is too pessimistic an estimate. In fact, on average the top bidder will have a value in excess of that of the second highest bidder. If you estimate the values of the third and lower bidders given the actual first and second highest estimates, affiliation implies that you would make a higher estimate than if you assume that the highest person's value was only equal to the second highest person's value. In the Japanese auction, the number two bidder will be able to infer the valuations of the third and lower bidders by seeing when

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[17] If everyone follows this strategy then whenever you win you will make a profit and whenever you lose you would have had to overpay to win. For example, if the true value is the average of two estimates then you would drop out when the bidding reached your value estimate. So if your value were 50 you would drop out at 50. If the other person dropped out at 40 then you would win, the true value would be 1/2 * (40 + 50) = 45, and you would make a profit of 5. But if the other person had a value of 60 and you decided to continue bidding until you "won" the auction then you would end up having to pay 60, assuming that your competitor followed the equilibrium strategy, and you would only get a property worth 1/2 * (50 + 60) = 55.

they drop out of the auction. So he or she will drop out of the bidding at a price based on the actual third and lower valuations rather on a conservative estimates.[18]

As an example, assume that there are three bidders. A's value estimate can be described as the sum of two random variables, A and X, each uniformly distributed between 0 and 36. Similarly, B and C have estimates of B + X and C + X where B and C are also uniformly distributed between 0 and 36. Each bidder knows either A + X, B + X, or C + X respectively, but does not know the random variables individually. If all the bidders could share information they would each value the asset at the average of A + X, B + X, and C + X. Assume, for example, that B and C have the two highest estimates, 36 and 45, respectively. In a sealed-bid Vickery auction, B would have to make an estimate of the signal of the lowest bidder assuming that each of the top two had values of 36. This estimate would turn out to be 24, so B would bid 1/3 * (24 + 36 + 36) = 32, which is how much the winner C would pay in the auction. But contingent on the two highest estimates actually being 36 and 45 rather than 36 and 36, the best guess for the low estimate is actually 27. In an English auction, the actual estimate of the low bidder would be revealed at the point where he or she drops out, and on average B will end up dropping out of the bidding at a price of 1/3 * (27 + 36 + 36) = 33.

Finally, there is the issue of why the first-price sealed-bid auction underperforms the Vickery or English auction when there are affiliated values. With independent values or affiliated values, the high bidder in the Vickery auction pays an amount based on the actual valuation of the second most optimistic bidder. With independent values in the first-price auction, the highest bidder bids her estimate of the second highest bidder's value, conditional on her having the highest value; hence equivalence in expected revenue. But in the first-price auction with affiliation, the person with the highest value will know that people with lower values will determine their bids based on an assumption that all other bidders will have very low (affiliated) values, and this leaves a margin for the top person to bid more conservatively.

We show this with a numerical example. Assume that there are two bidders A and B, where A's (private) value is A + X and B's private value is B + X. A knows A + X but does not know either independently, and similarly for B. A, B, and X are all uniformly

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[18] An English auction is almost as good but not quite: since you don't know if someone is still bidding, you are not able to tell exactly when they dropped out. While the top two bidders are obviously in competition, all the lower bidders may or may not still be in the game.

distributed between 0 and 36, as in our previous example. In a Vickery (or Japanese or English) auction the seller will earn the minimum of A + X and B + X, which is the expectation of X plus the expectation of the minimum of A and B. Since the expectation of X is 18 and the expectation of the minimum of A and B is 12, the expected revenue from the auction is 30. However, in a sealed-bid auction, each bidder will only bid 2/3 of his or her value. Since the expected highest value is the expected value of X plus the expected maximum of A and B; the expected high value is 42 and the expected revenue from the auction is 2/3 * 42, or 28. Therefore, the expected additional profit from switching from a first-price auction to a Japanese auction is 2/28, or just over seven percent, in this example.

APPENDIX B:

The Efficient Auction Design

In this section we discuss the design of an "ideal" auction. In a world of rational bidders, each with a clear understanding of the auction rules, this auction would always result in an efficient outcome. The problem is that this design may be too complicated for practical implementation. *Because of the complexity, we do not propose this scheme for the PCS auction.* We present it as a basis of comparison with our proposed scheme.

We begin with the question: what is the efficient outcome? Imagine each bidder were to reveal his or her absolutely truthful valuation for each of the licenses. Bidders have a value for each regional license and for a national license. Because of economies of scale, the value of a national license might exceed the sum of the regional licenses. For a firm primarily interested in a national network, the national valuation could be much larger than the sum of its regional valuations. For some regional bidders, the value of MTA licenses outside its region values might be zero.

This valuation is a vector describing the value for each region and the value for a national license. For example, if the country is divided into 3 regions, then each bidder presents his or her value for each of three regions and for a national license.[19] The division into three regions rather than the 49 MTAs or 487 BTA regions is made solely for notational simplicity and does not effect any of the results. The valuation vector of firm i can be represented as $V_i = (v_1^i; v_2^i; v_3^i; v_n^i)$ where v_1^i is bidder i's valuation in region 1, v_2^i is i's valuation in region 2, v_3^i is i's valuation in region 3 and v_n^i is i's valuation for a national license. Note that the national valuation is mutually exclusive of

[19] For simplicity, we begin with the case where combinatorial bidding is restricted to national licenses. We then show how the arguments extend to fully general combinatorial bidding below.

the regional valuations; the regional values are all conditional on not having a national license.

Imagine that the FCC had these truthful valuations from each firm. What would be the efficient allocation? Given a fixed number of licenses, they would choose to distribute them so as to maximize the sum of the valuations. We describe the allocation system in detail in order to introduce the notation used in calculating payments. To be concrete, we focus on the two 30 MHz bands, A and B.[20] For simplicity, we describe the result when there are 10 bidders. The allocation rule works as follows.

First consider the maximal sum if no national licenses are awarded, denoted by R_0,

$$R_0 = \text{Top 2 of } (v_1^1; v_1^2; v_1^3; \dots; v_1^{10}) +$$

$$\text{Top 2 of } (v_2^1; v_2^2; v_2^3; \dots; v_2^{10}) +$$

$$\text{Top 2 of } (v_3^1; v_3^2; v_3^3; \dots; v_3^{10}).$$

Then consider the maximal sum if exactly one national license is awarded, denoted by R_1,

$$R_1 = \text{Max over i of } \Big[v_n^i + \text{Max excluding i of } (v_1^1; v_1^2; v_1^3; \dots; v_1^{10}) +$$

$$\text{Max excluding i of } (v_2^1; v_2^2; v_2^3; \dots; v_2^{10}) +$$

$$\text{Max excluding i of } (v_3^1; v_3^2; v_3^3; \dots; v_3^{10}) \Big].$$

To put this in words, if the government allocates a national license to bidder 1 then the total valuation is v_n^1 plus the maximum valuation from allocating

[20] The analysis for the 10 MHz licenses follows a parallel argument.

the remaining license among the bidders other than person 1. We consider this sum for all possible allocations of the one national license and choose the allocation that leads to the highest total. *Note that the national license need not go the person with the highest national bid.* That person may have won many of the regional licenses and taking away these regional licenses and replacing them with a national license may or may not be the most efficient allocation of the national license. While it is difficult to figure out by hand each of the R_1 values, it is a simple matter for a computer program to calculate the allocation that maximizes the sum of the values.

Next consider the maximal sum if both licenses are awarded nationally. R_2 is the sum of top two highest national bids.

$$R_2 = \text{Maximum over } i; j \text{ of } v_n^i + v_n^j.$$

The licenses are allocated based on the which is highest, R_0, R_1, or R_2. Let us call this maximum value R^*.

There are two presumptions about this efficient auction technique that remain to be addressed. First, is it possible to give everyone an incentive to reveal their true valuations? Second, given that it is possible, would the FCC actually want to implement this scheme?

It is remarkable that it is indeed possible to design an auction that in theory will lead all the bidders to reveal their true valuations. The solution is that each bidder gets a surplus equal to the marginal surplus brought to the system by his or her announced valuations. What the bidder pays is his or her valuations for the licenses received net of this surplus.

We explain this in more detail. Imagine for a moment that bidder 1 does not participate in the auction. We calculate the efficient allocation without bidder 1. The total value of this allocation we denote by R^*_{-1}, the value of R^* without person 1. We then compare this to the value when bidder 1 does participate, R^*. It is the case that R^* is greater than R^*_{-1} if and only if bidder 1 is allocated some of the licenses. In that event, bidder 1 pays his or her announced valuations for the licenses received minus $(R^* - R^*_{-1})$. Another way of putting this is that the bidder gets to keep as profit from the auction an amount equal to $R^* - R^*_{-1}$: this is the amount paid that is less than the value received.

For each bidder, we consider the efficient allocation with and without that bidder. Bidder i gets the licenses according to the most efficient allocation, pays his or her true valuation for these licenses net of the marginal surplus, $R^* - R^*_{-i}$. Under this scheme, everyone has a dominant strategy to reveal the true valuations; it is better to reveal the truth no matter what other strategies other bidders follow.[21]

Although this scheme may seem quite complicated, the result is more intuitive and more familiar in a simplified version of the auction. Consider the above formula in an auction in which we only permit regional bidding. In this auction, if everyone bids truthfully, the efficient solution is straightforward: assign the regional license to the two highest bidders. But how much should these winning bidders pay? The answer depends on how much surplus do they bring to the system. If one of the winning bidders were to disappear, then the next highest bidder would be awarded a license. Thus the surplus is the difference between the winning person's valuation and the highest valuation that doesn't get a license. What this means in terms of payments is that each of the winning bidders must pay the value of the highest losing bidder. This payment system gives everyone an incentive to bid their true valuation no matter what others are doing. Note that this type of payment scheme is better known as a "second-price" or Vickrey auction. Exactly this scheme is what being used on an experimental basis for the sale of Treasury bills. Our results are the generalization of the Vickrey auction when combinatorial bidding is allowed.

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[21] There is still the winner's curse effect. The bidder's truthful valuations are made conditional on having one of the two highest valuations, or more generally, on having won the auction.

The above discussion focused on only one type of combinatorial bidding for a national license. To extend the auction design to allow combinatorial bidding for any combination of licenses, the FCC would allocate licenses so as to maximize the total valuations. Although there are efficient ways of searching, the basic idea is to consider all feasible combinations of allocations and choose the set of bids that leads to the highest combined valuation. The payments are not the bids but rather the announced valuations minus the difference between the maximum total valuation with the bidder and without the bidder. In the language of Pratt and Zeckhauser (1978), each bidder pays the externality of his or her bid.

To an economic theorist, the above auction design is not a difficult concept. However, experience has shown that even economics Ph.D. students have trouble understanding the above description. The system of payments that leads to an efficient allocation is quite subtle. In the case with only one item to sell and no regional versus national issues, the design reduces to a Vickrey or second-price auction . Even this is complicated compared to an English ascending or sealed-bid auction. The problem is that if people do not understand the payment rules of the auction then we do not have any confidence that the end result will be efficient.

Describing the auction by its rules makes it seem more complicated that it is. We offer an example below to help clarify the theoretical description of the rules given above. In the example we continue with the case where there are only three regions, two licenses for each region, and ten bidders. Bidders 1–6 are national firms; they are willing to pay a premium for a national license. Bidders 7–10 are regional; they are only interested in licenses for one or two regions. Given that firms bid their true valuations, how does the efficient auction mechanism allocate the licenses?

First we consider a purely regional allocation. The winning bids are the two highest in each region. The total revenue is 235 as seen in allocation below with the winning bids in bold type.

	Region 1	Region 2	Region 3	National
Bidder 1	30	30	25	110
Bidder 2	20	15	15	55
Bidder 3	30	0	**30**	75
Bidder 4	10	25	10	65
Bidder 5	**65**	**35**	20	125
Bidder 6	10	15	25	50
Bidder 7	25	0	**30**	0
Bidder 8	**35**	0	0	0
Bidder 9	0	**40**	0	0
Bidder 10	0	25	20	45
REVENUE	100	75	60	—

Next consider granting a single national license. The maximum revenue is attained by giving the national license to bidder 1. The remaining regional license is granted to the highest bid in each region. The allocation follows below with the winning bids in bold type:

	Region 1	Region 2	Region 3	National
Bidder 1	30	30	25	**110**
Bidder 2	20	15	15	55
Bidder 3	30	0	30	75
Bidder 4	10	25	10	65
Bidder 5	**65**	35	20	125
Bidder 6	10	15	25	50
Bidder 7	25	0	**30**	0
Bidder 8	35	0	0	0
Bidder 9	0	**40**	0	0
Bidder 10	0	25	20	45
REVENUE	65	40	30	110

Total revenue from this allocation is 245. Note that bidder 1 is willing to pay a large premium to attain a national license. If instead we gave the national license to the highest bidder, bidder 5, the total value of the licenses would fall to 240, the reason being that we have lost the value of bidder 5 in the regional auctions. Although the highest bidder might not win a national license, this will only occur if the firm would otherwise have won some of the regional licenses.[22]

Next we consider allocating two national licenses. The maximal revenue allocation with two national licenses, illustrated below, brings 235 in revenue. Therefore, the efficient allocation is to issue one national license to bidder 1 and regional licenses to bidders 5, 7, and 9.

	Region 1	Region 2	Region 3	National
Bidder 1	30	30	25	**110**
Bidder 2	20	15	15	55
Bidder 3	30	0	30	75
Bidder 4	10	25	10	65
Bidder 5	65	35	20	**125**
Bidder 6	10	15	25	50
Bidder 7	25	0	30	0
Bidder 8	35	0	0	0
Bidder 9	0	40	0	0
Bidder 10	0	25	20	45
REVENUE	—	—	—	235

[22] This peculiarity of the efficient auction design is the type of complication that could confuse the bidders and frustrate its implementation. To some people, denying a high bidder the license would not seem fair.

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